

# ***RP-21 Steering Committee Meeting***

## ***NASA In-Space Propulsion Update***

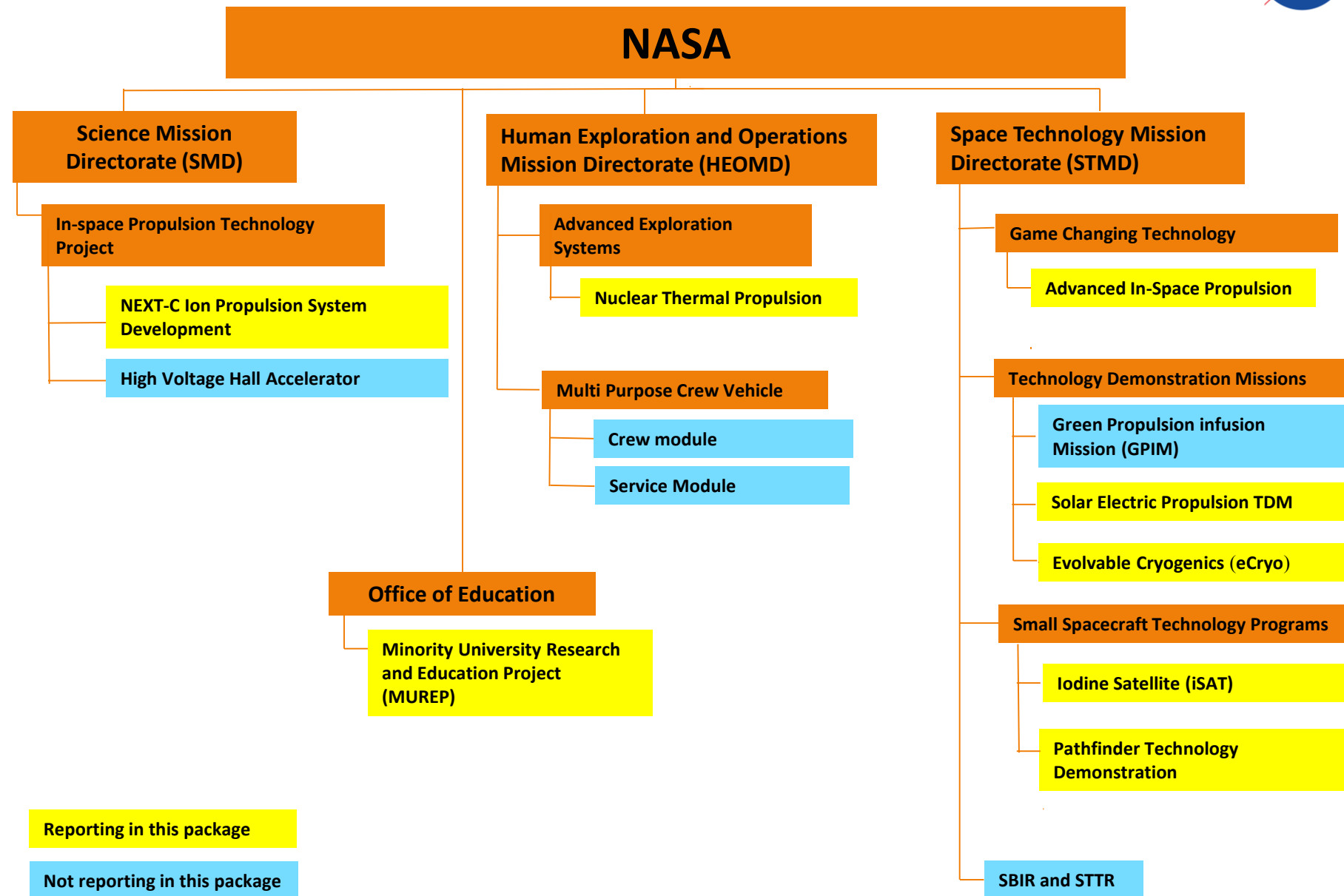
**13 August 2015**

**Mark Klem**

**NASA Glenn Research Center**



# NASA Spacecraft Propulsion Sponsorship





# **NASA Science Mission Directorate (SMD)**



# NEXT-C Ion Propulsion

## NEXT-Commercial (NEXT-C)

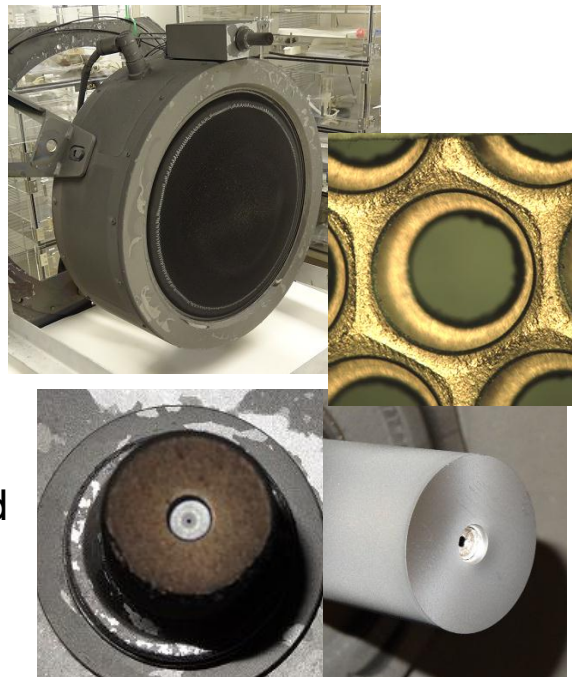
- NASA has formed the NEXT-C Project and completed the procurement process for cost-shared development of flight hardware
  - Prime Contractor: Aerojet Rocketdyne
  - Major Subcontractor: ZIN Technologies
- Contract scope includes:
  - Completion of power processing unit technology development to TRL6
  - Fabrication, test and delivery of two NEXT-C thrusters and PPUs
- SMD has offered this flight hardware to mission users through the Discovery 2014 Announcement of Opportunity (AO)
- Project Schedule:
  - SRR completed July 16 2015
  - PDR: January 2016
  - CDR: November 2016
  - HAR: January 2019

# NEXT-C Ion Propulsion System

## In-house Support of NEXT-C Contract – Status

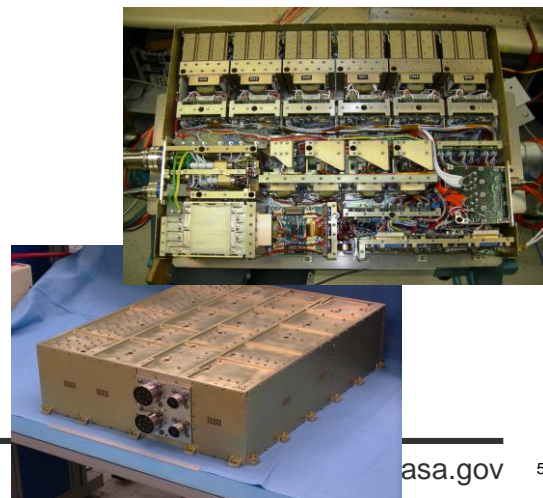
### • Thruster

- NEXT Long Duration Test post-test destructive evaluation in progress
  - Findings will be used to verify service life models & identify potential design improvements
- Cathode heater fabrication initiated for cyclic life testing
- Thruster operating algorithm definition & verification initiated to provide operating procedures for mission users
- High voltage propellant isolator life test voluntarily terminated after successfully operating 51,200 h



### • Power processor unit (PPU)

- Replaced all problematic stacked multilayer ceramic dual inline pin capacitors within PPU Testbed
- Rebuilt & installed discharge power supply primary power board
- Completed full functional performance characterization
  - Final test report in progress
- Transferred PPU Testbed to contractor to support prototype design effort





# **Space Technology Mission Directorate (STMD)**



# **Solar Electric Propulsion(SEP) Technology Demonstration Mission (TDM) Project**

- NASA is developing a high-power SEP systems required to move large masses in interplanetary space as part of a multi-use, evolvable space infrastructure
- NASA is maturing mission design for a 50kW-Class SEP Demonstration
  - Most mature concept is the Asteroid Redirect Robotic Mission (ARRM)
- NASA is developing the requisite technologies for the SEP TDM, including ARRM, to enable these SEP missions and applications at higher power levels
  - HERMeS is a 12.5 kW Hall thruster co-developed by GRC and JPL for operation up to 3000 s specific impulse and a 50 kh lifetime that is enabled through the use of magnetic shielding
  - HP-120V PPU is a 13.3 kW full-bridge topology PPU capable of operating the HERMeS thruster at the 12.5 kW, 3000 s operating point and demonstrated efficiencies up to 95.5%
- An Ion Propulsion System design has been developed for the Asteroid Redirect Vehicle utilizing a 3 + 1 EP string architecture based on the NASA in-house developed technologies and their demonstrated performance
- Acquisition for most major IPS components has been initiated to meet the Dec. 2020 ARRM launch date (EP strings, xenon tank, xenon propellant in planning)

# Game Changing Development (GCD) Advanced In-Space Propulsion Project

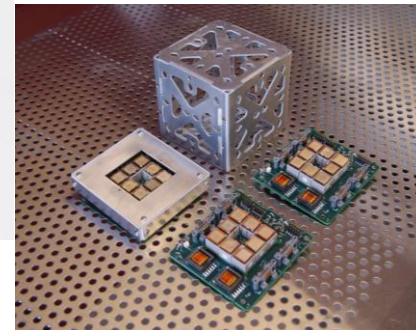
## ***Microfluidic Electrospray Propulsion (MEP)***

**Awarded under NRA NNL12A3001N: Appendix D**

- MIT: Scalable Ion Electrospray Propulsion System (S-iEPS) – Contract completed and 3 deliverable units provided to NASA GRC
- Busek: HARPS thruster (High Aspect Ratio Porous Surface) – Contract completed and 3 deliverable units provided to NASA GRC
- JPL: Microfluidic Emitter with indium – Contract granted no-cost extension until Aug 31, 2015
- Busek and MIT units are at NASA GRC for testing. Testing planned for Aug-Sept 2015.



Busek HARPS



MIT S-iEPS

## ***Iodine 600W Hall Thruster***

- Phase III SBIR contract awarded to Busek in April
- Busek delivered thruster to GRC from Phase II. Testing underway in GRC Vacuum Facility-7 (VF-7)
- System requirements completed for Power Processing Unit development

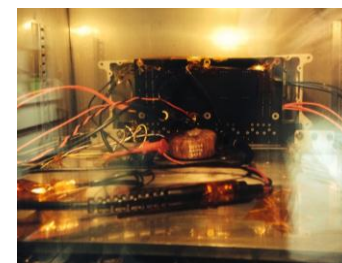


Busek BHT-600

## ***High Temperature Boost Power Processing Unit***

- High temperature operation with lowered switching loss at high frequency to reduce mass and volume with comparable or better efficiency
- Prototype 2.5kW discharge module tested at 100C with 300Vin and 800Vout. Demonstrated >97% efficiency
- Project continuation review in Sept for additional 2 years

HTB PPU discharge board during 100C ambient test at JPL







# Small Spacecraft Technology Program (SSTP)

## Iodine Satellite (iSAT)

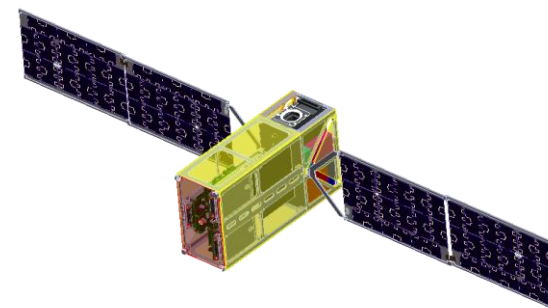
- NASA MSFC is leading the flight system and spacecraft development
- NASA GRC is propulsion system lead (leveraging GCD AISP investments for modular PPU)
- Spacecraft and mission design:
  - 12U CubeSat. Demonstrate plane and altitude changes during a 90 day mission
  - 200W Busek iodine Hall propulsion system. Combination of Air Force and NASA SBIR contracts for propulsion system development
  - Initial 200W thruster testing underway at NASA GRC. Iodine feed system development in process at NASA MSFC
- Mission CDR planned for Fall 2015



iSAT Preliminary Concept Design

## Pathfinder Technology Demonstration

- NASA ARC is leading the flight system and spacecraft development
- NASA GRC is propulsion system lead
- 6U CubeSat spacecraft bus to be operated by NASA for new propulsion or other technology sub-systems demonstrations.
- Multiple propulsion systems under evaluation for first mission
- NASA released Request for Information (RFI) for spacecraft development options



Pathfinder Concept Design



# Evolvable Cryogenics (eCryo) Project

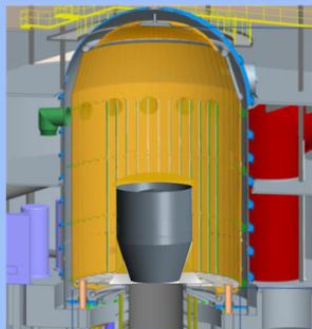
**Develop, integrate, and validate cryogenic fluid management technologies (CFM) at a scale relevant to and meeting the mission needs for NASA missions and SLS/Stages**

## Objectives:

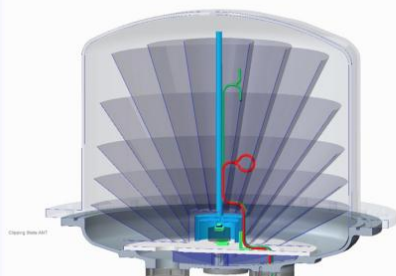
- Technology development for extended missions focused on the needs of the SLS upper stage.
- Evolutionary development of new technology demonstrating near term gains which are shared with industry.
- Increase capabilities of analysis tools to perform predictive simulations for missions with in-space cryogenic systems.

## Technology Demonstrations:

- Use existing Agency assets and infrastructure to mature cryogenic propellant technologies
  - Testing ranges from components to entire systems
  - Scale of testing will be limited only by facility capabilities.
- Subsystem tests and system tests need not use flight-like components



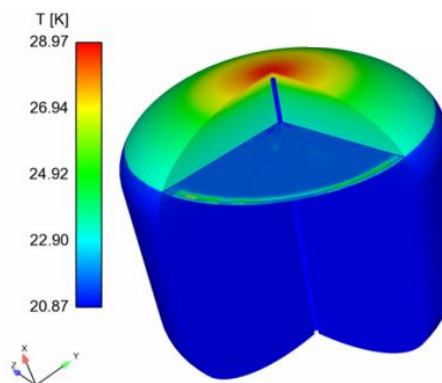
**SHIVER Test Article**



**RFMG for RRM3 Mission**

## Products:

- **Structural Heat Intercept Insulation Vibration Evaluation Rig (SHIVER):** Implement vapor cooling and multilayer insulation onto a large liquid hydrogen tank that is representative of a cryogenic stage.
- **Development & Validation of Analysis Tools (DVAT):** Advancement of numerical tools to cover cryogenic fluids in both settled/unsettled conditions.
- **Radio Frequency Mass Gauge for the Robotic Refueling Mission 3 (RFMG for RRM3):** Test and demonstrate RFMG technology on the GSFC RRM3 at the International Space Station (liquid methane).
- **Improved Fundamental Understanding of Super Insulation (IFUSI):** Improve the capability of designing cryogenic multilayer insulation blankets for large cryogenic upper stages.
- **Integrated Vehicle Fluids (IVF):** Evaluate the extensibility of the IVF concept for use on the Exploration Upper Stage (EUS).



**DVAT: CFM Analysis**



**SLS/Stages**

## Team:

GRC (lead), MSFC

Industry Partners: TBD

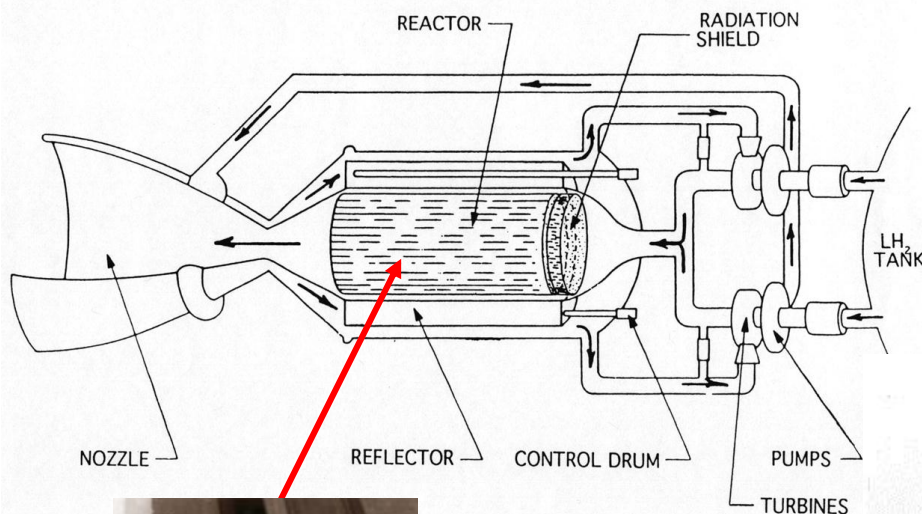
International Partners: CNES providing comparative analysis of CFM.



# **HEOMD Advanced Exploration Systems (AES)**

# Nuclear Thermal Rocket (NTR) Concept Illustration (Expander Cycle, Dual LH<sub>2</sub> Turbopumps)

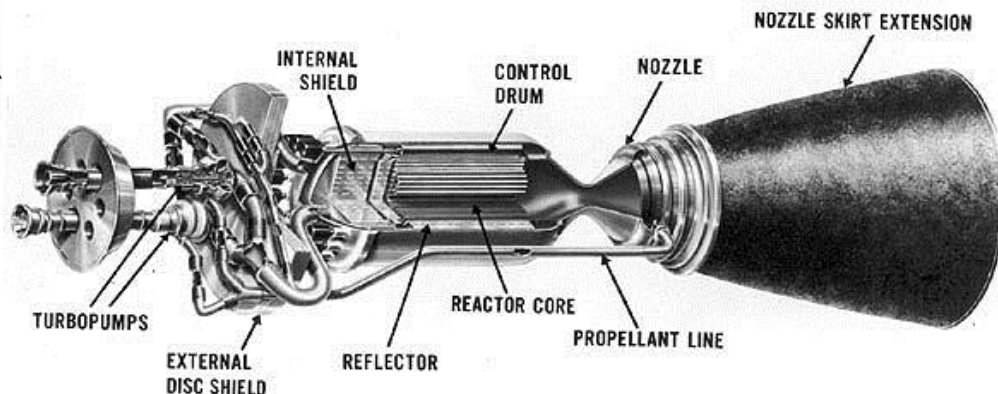
**NTR:** High thrust / high specific impulse (2 x LOX/LH<sub>2</sub> chemical) engine uses high power density fission reactor with enriched uranium fuel as thermal power source. Reactor heat is removed using H<sub>2</sub> propellant which is then exhausted to produce thrust. Conventional chemical engine LH<sub>2</sub> tanks, turbopumps, regenerative nozzles and radiation-cooled skirt extensions used -- ***“NTR is next evolutionary step in high performance liquid rocket engines”***



*During his famous Moon-landing speech in May 1961, President John F. Kennedy also called for accelerated development of the NTR saying this technology “gives promise of some day providing a means of even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself.”*



Rover / NERVA "Composite" Fuel



The NTR uses high temperature fuel and produces ~560 MWt (for ~25 klb<sub>f</sub> engine) but operates for ≤ 80 minutes on a round trip mission to Mars (DRA 5.0)



## Overview of NTP Development Activities by NASA and DOE

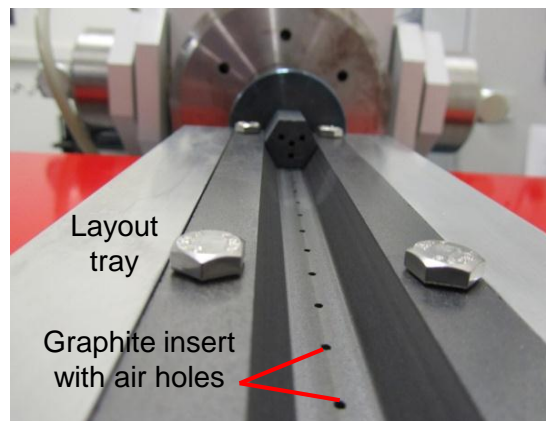
- In FY11, NASA formulated a plan for Nuclear Thermal Propulsion (NTP) development that included 2 key elements – “**Foundational Technology Development**” followed by “**Technology Demonstrations**”
- The ongoing NTP project, funded by NASA’s Advanced Exploration Systems (AES) program, is focused on Foundational Technology Development and includes 5 key task activities:
  - (1) Fuel element fabrication and non-nuclear validation testing of “heritage” fuel options;
  - (2) Engine conceptual design;
  - (3) Mission analysis and engine requirements definition;
  - (4) Identification of affordable options for ground testing; and
  - (5) Formulation of an affordable and sustainable NTP development program
- Performance parameters for “Point of Departure” designs for a small “criticality-limited” and full size 25 klb<sub>f</sub>-class engine were developed using heritage fuel element designs for both Rover/NERVA Graphite Composite (GC) and Ceramic Metal (Cermet) fuel forms
- To focus the fuel development effort and maximize use of its resources, the AES program decided, in FY14, that a “leader-follower” down selection between GC and Cermet fuel was required
- An Independent Review Panel (IRP) was convened by NASA and tasked with reviewing the available fuel data and making a recommendation to NASA. In February 2015, the IRP recommended and the AES program endorsed GC as the leader fuel
- At the direction of NASA HQ (3/25/15), by the end of FY’ 17, NASA and DOE are to work together to formulate a detailed DDT&E plan allowing the affordable development of a small (~7.5 – 16.5 klb<sub>f</sub>) GC engine for possible flight technology demonstration (FTD) mission within a 10-year timeframe
- NASA and DOE are currently focused on fabricating and testing a partial length GC fuel element before the end of FY15



## Equipment Assembled at ORNL for the Fabrication of Graphite Composite (GC) Fuel Elements



Graphite FE extruder with installed vent lines for DU capability



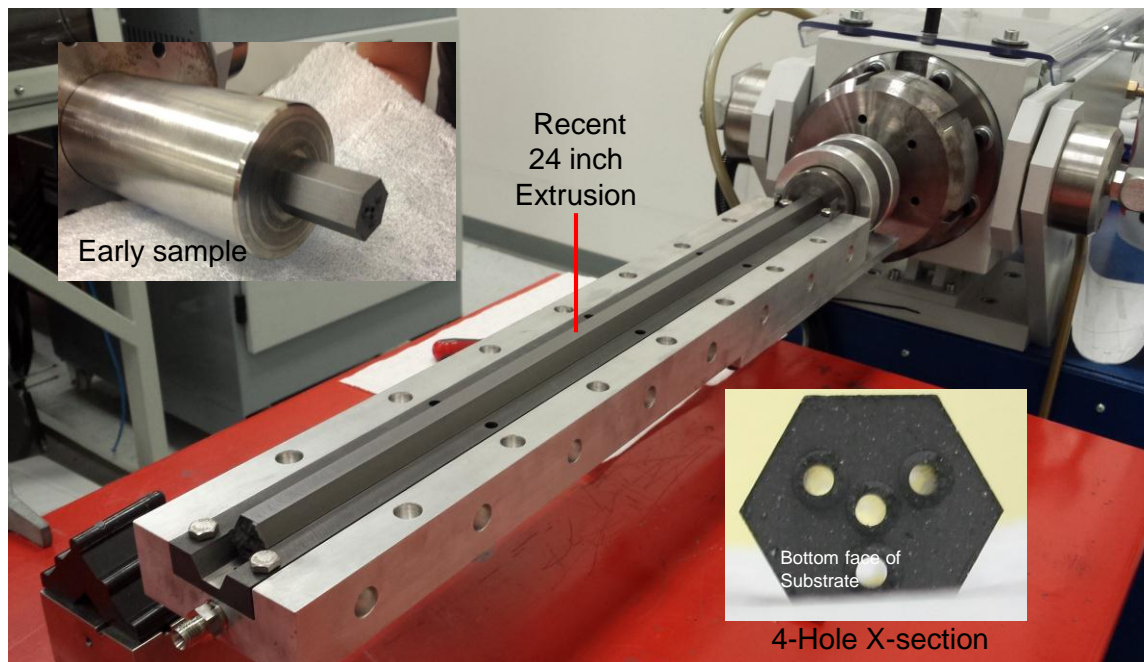
Layout tray

Graphite insert with air holes



19 and 4-Hole Extrusion Dies

Extruder with 4-Hole Die



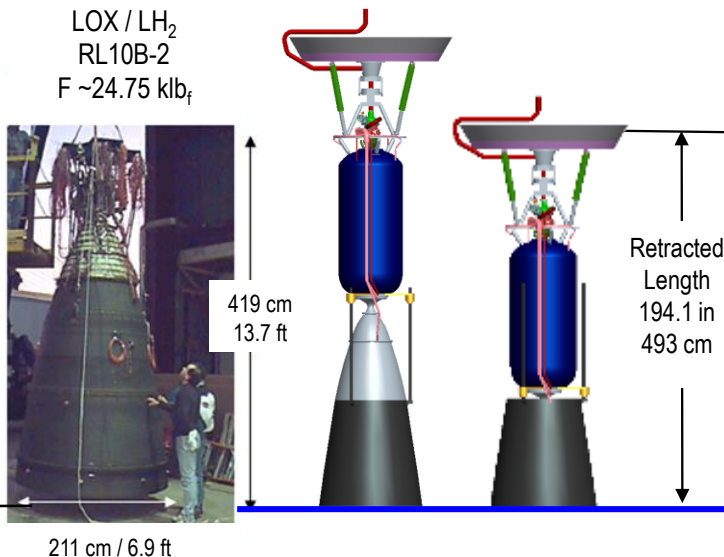
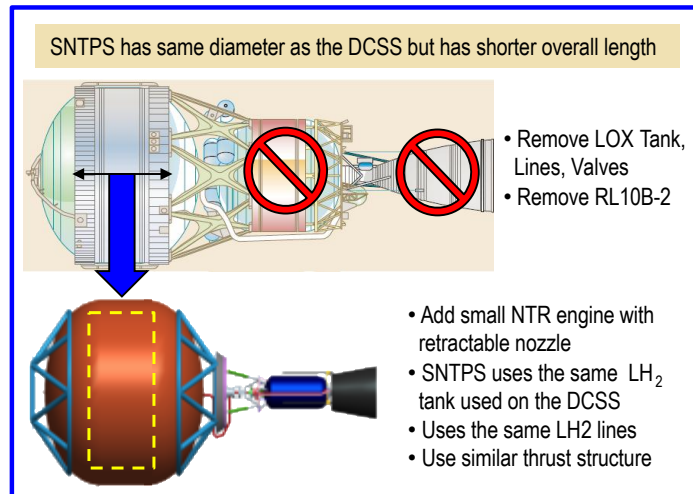
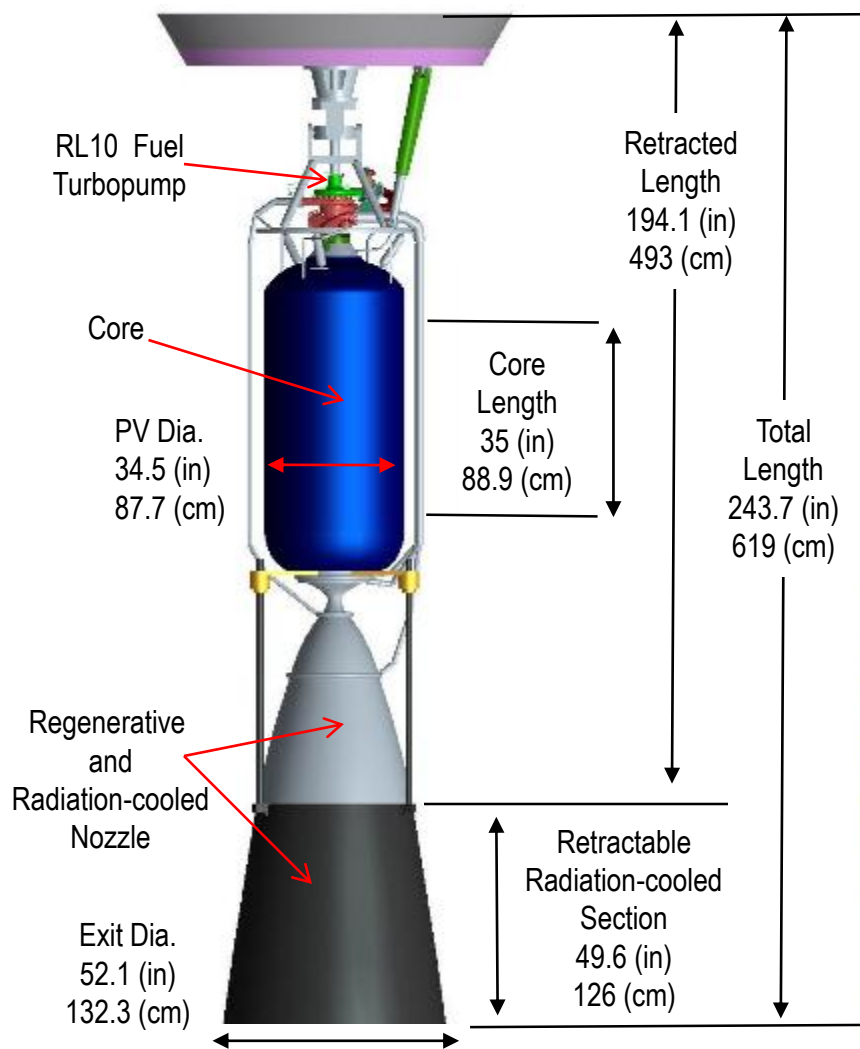
Recent 24 inch Extrusion

Early sample

Bottom face of Substrate

4-Hole X-section

# Small 7.5 klb<sub>f</sub> NTP Engine and Stage for **Notional** 2025 Lunar Flyby FTD Mission





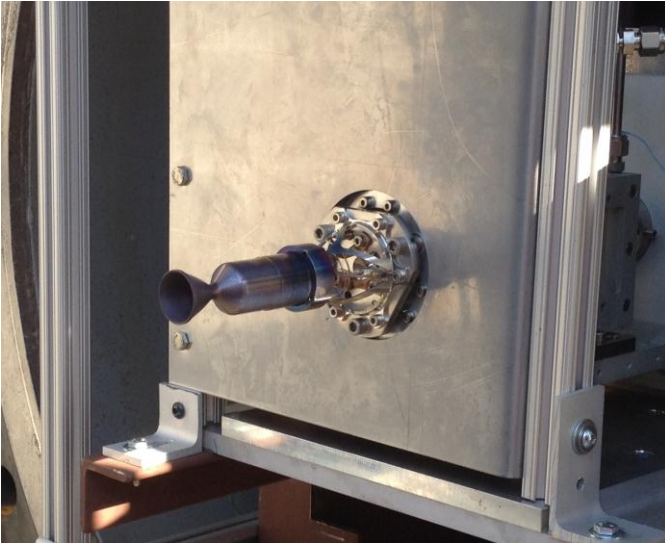
## **Other NASA Activities**

**AF-M315E and LMP-103S Small Thruster and  
Tank Maturation Efforts at MSFC**



# LMP-103S Thruster Testing

## March 2015 testing of 22N and 5N ECAPS LMP-103S Thrusters



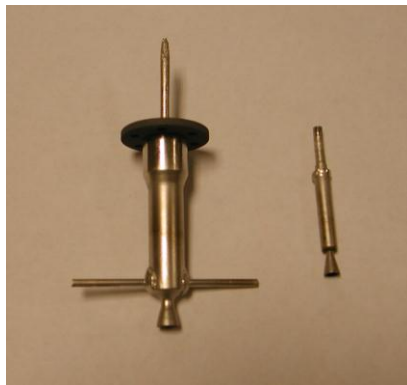
22N Thruster



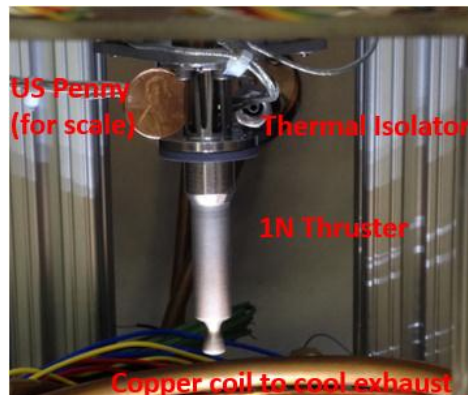
5N Thruster

The 5N Thruster (loaned by Orbital/ATK) has initially hot-fired to verify facility systems. The 22N thruster was fired 35 times under varying conditions into a 0.3 psia vacuum. Performance will be assessed using thrust, propellant flow, pressure and temperature (including IR) data collected during the tests.

# AF-M315E Thruster Testing



1N and 0.1 N Thrusters



1N Thruster installed in test facility

Hot Fire testing of a 1N Thruster was attempted as a summer Intern Project 2014

Testing is resuming July 29, 2015

- Thrusters designed and manufactured by Plasma Processes Inc.
- Planned pulse durations of 1 second to 10 seconds
- Vacuum environment of 2 psia
- Initially will not measure thrust or flowrate. These will be added as testing progresses

# Additive Manufactured Propellant Tank

A preliminary Cubesat sized propellant tank has been designed at MSFC and manufactured by three different vendors using titanium. Tank includes an internal “sponge” to function as a propellant management device. Tank is designed for 400 psig and to mount a 0.1N thruster partially recessed within the center hole. Structural and thermal testing is planned.



Three tanks from three different vendors manufactured June 2015.



Same tanks cut open to show internal quality of construction.



# **Minority University Research and Education Project (MUREP) Institutional Research Opportunity Center for Space Exploration and Technology Research (MIRO cSETR)**

# MIRO Center for Space Exploration and Technology Research

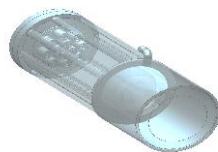
## The University of Texas at El Paso



MIRO Center for Space Exploration and Technology Research (MIRO cSETR) supports NASA's vision of space exploration by focusing on advanced capabilities in the areas of non-toxic and green propulsion

- ❑  $\text{LO}_2/\text{CH}_4$  based propulsion technologies for in-space propulsion and ascent and descent engines
- ❑ Ammonium Dinitramide (ADN), Hydroxylammonium Nitrate (HAN), and High-Test Peroxide (HTP) based green propulsion technologies for in-space propulsion

- Additive Manufacturing (AM) Capability Demonstrations and Maturation
- $\text{LOX}/\text{Methane}$  Engine Technology Maturation
- Affordable Engine Development and Test



2000 lb<sub>f</sub> Deep Throttlable  
 $\text{LO}_2/\text{CH}_4$  e Engine

- Integrated  $\text{LOX}/\text{Methane}$  RCS Technology Demonstration
- AM Capability Demonstration for Low Cost RCS Development



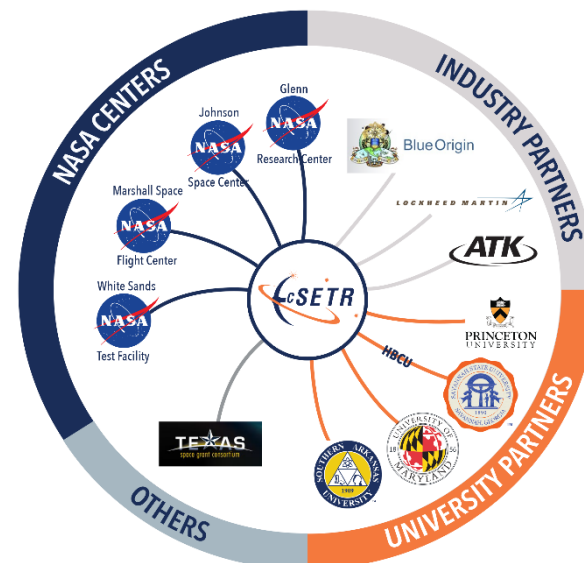
$\text{LO}_2/\text{CH}_4$  RCS

- Flight Demonstration of  $\text{LOX}/\text{Methane}$  Main Engine and Integrated RCS Technologies
- Composite Tank and Structure
- SOFC Power Integration
- AM Capability Demonstration for Vehicle Components



Suborbital Test Bed

- ADN and HTP based 5 lbf, 1 lbf, and 0.1 lbf class green propellant engines
- System level integration for in-space demonstrations



### Propulsion Research Infrastructure

- Ultra High Velocity Projectile Resistance Combustion Bunker
  - 600 ft<sup>2</sup> test space
  - Fully instrumented remote control operation
  - Altitude Simulation System
  - Two-stage ejectors with 70,000 - 200,000 ft continuous altitude capability
- Torsional Thrust Balance
- Cryogenic Propellant Delivery System
- Cryogenic Methane Production System
- HTP, LMP 103s, and AF-M315E propellants storage, handling and delivery systems
- Multi-Fuel Manifolds and Feed Systems for Liquid and Gaseous Fuels
- High Pressure Optically Accessible Rocket Combustors
- Rocket Cooling Channel Test Facility

### Instrumentation

- High-Speed Particle Image Velocimetry
- Stereo-Particle Image Velocimetry
- Laser Doppler Velocimetry
- Phase Doppler Particle Analyzer
- Laser Induced Fluorescence
- Color Schlieren Deflectometry
- Ultra High Speed Intensified Imaging
- Emission Analyzers, Gas Chromatograph, Laser Flash Apparatus, Thermogravimetric Analyzer, Differential Scanning Calorimeter, and mass spectrometer

FY 15: A \$9.3 M new NASA MIRO Program and Industry Research Award  
FY09-13: \$11 M Research Awards

